Health and conservation implications of Australian bat *Lyssavirus*

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ABSTRACT

Australian bat *Lyssavirus*, first reported in mid-1996 from a Black Flying Fox *Pteropus alecto* has now been isolated from two other species of flying fox, a microbat and a human, who died of a rabies-like illness. Infected animals have been identified from widely separated localities in four Australian states. It is not known definitely from which species of animal the human victim contracted the disease, which is (are) responsible for spreading it, nor whether it is an old disease or one that has recently entered Australia.

The infectivity of Australian bat *Lyssavirus* to humans and other mammals is not known, but its close genomic and antigenic relationship to classical rabies virus suggest that it is likely to be capable of causing fatal illness in most mammalian species. Its similarity to classical rabies virus also indicates that humans and other mammals will be protected by existing rabies vaccines. The discovery of *Lyssavirus* in Australian bats has highlighted the need for professional and community groups involved with wild animals to work together to decrease the risks to human health and to lessen the impact on bats and other native species. Educating the public about the risks of contact with bats is the single most important safeguard in protecting humans from a bat-borne disease. Concurrently, people need to be informed of the important role of bats in maintaining biodiversity and ecosystem integrity to minimize public impact on bats.

OVERVIEW OF LYSSAVIRUSES

The best known of the lyssaviruses is that which causes classical rabies, one of the most feared and respected of the zoonoses — animal pathogens that affect humans (Kunz *et al.* 1996). Classical rabies has been known from the Middle East since before 2 300 BC, and is now known to occur on every continent, except Australia and Antarctica (Brass 1994; Fishbein and Bernard 1995). Worldwide an estimated 40 000–100 000 human deaths are caused by classical rabies virus each year, mostly from dog bites (>90%) and mostly in developing countries (99%), where health care is minimal (Smith and Seidel 1993; Brass 1994; Fishbein and Bernard 1995; Rupprecht *et al.* 1995). Only a few humans die of rabies in the US each year, but the annual cost of prevention of the disease is estimated to be in the region of US$300 million, most of which is spent on animal vaccination (Smith and Seidel 1993; Rupprecht *et al.* 1995), with US$45 million being spent on human vaccination (Anon. 1995b). Blood-feeding Vampire Bats *Desmodus rotundus* cause serious outbreaks of human rabies in South and Central America (e.g., Lopez *et al.* 1992) and the annual cost to the cattle industry is immense, although difficult to calculate because of unco-ordinated reporting (Brass 1994). Many other mammals, including bats, cat, coyotes, ferrets, foxes, jackals, mongooses, primates, raccoons, raccoon dogs, skunks and shrews (Constantine 1988; Brass 1994; Fishbein and Bernard 1995; Krebs *et al.* 1995) can also contract or transmit rabies to humans or other species.

Classical rabies virus is one of a group of closely related viruses in the genus *Lyssavirus* in the family Rhabdoviridae; other species known prior to 1996 were: Lagos bat; Mokola; Duvenhage and European bat 1 and 2 (Krebs *et al.* 1995; Rupprecht *et al.* 1995). All but Lagos bat virus are known to have caused rabies-like illness and deaths in humans (Brass 1994; Fishbein and Bernard 1995; Krebs *et al.* 1995). Few fatalities have been documented, but this may be in part because the disease cannot be distinguished from classical rabies unless modern diagnostic tests are applied. In Africa and Asia it seems almost certain that much information about non-classical rabies lyssaviruses is masked by the almost ubiquitous presence of classical rabies (Aghomo *et al.* 1990; Rupprecht *et al.* 1995). In Europe the existence of two variants of bat-borne *Lyssavirus* was not recognized until very recently (Baer and Smith 1991).

Non-rabies lyssaviruses are found in various species of mammal, particularly bats (Brass 1994; Rupprecht *et al.* 1995). Lagos bat virus

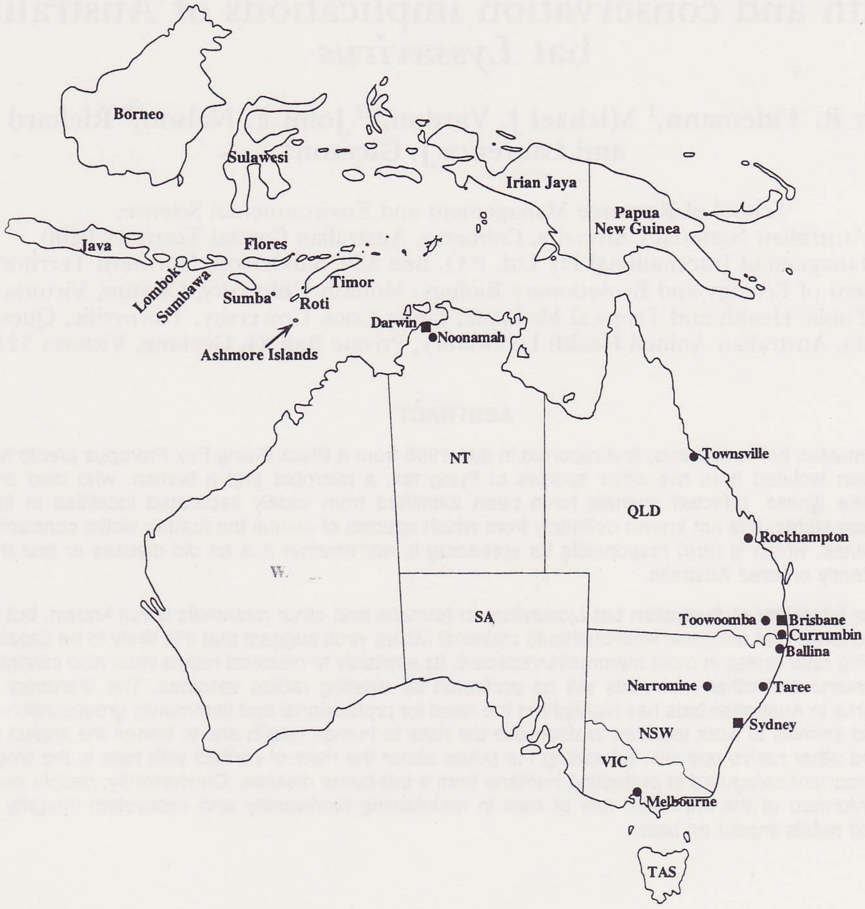


Figure 1. Location of bats found infected with Australian bat *Lyssavirus* (solid circles) and other localities mentioned in text.

has been identified in African fruit bats *(Eidolon helvum, Micropteropus pusillus, Epomorphorus wahlbergi)*, dogs and cats. It is the only one of the group that is not known to have caused human death, but this could be because of confusion with classical rabies. Mokola virus has been identified in African shrews (*Crocidura* spp.) and rodents (*Lophuromys sikapus* and *Tatera leucogaster*), and dogs and cats. Duvenhage virus has been found in African Slit-nosed Bats *Nycteris thebaica* and unidentified insectivores. It has not been identified in domestic animals. The European bat lyssaviruses have been found in many species of microbat, particularly *Eptesicus serotinus* and *Myotis* spp., and, although human deaths have occurred, neither is known to infect dogs or cats.

Australian bat *Lyssavirus* was first isolated in May 1996 from a juvenile Black Flying Fox *Pteropus alecto* from northern New South Wales (Fraser *et al.* 1996 a,b) and in November of the same year it caused a human fatality in an animal handler from central Queensland (Allworth *et al.* 1996; Lyssavirus Expert Group 1996). It has now been isolated from other *P. alecto*, from Little Red Flying Foxes *P. scapulatus*, Grey-headed Flying Foxes *P. poliocephalus* and a Yellow-bellied Sheathtail Bat *Saccolaimus flaviventris* from widely separated locations on the continent (Fig. 1). The *Lyssavirus* isolated in Australia is a new serotype (Fraser *et al.* 1996b; Lyssavirus Expert Group 1996; Gleeson 1997), but fortunately the treatments and vaccines developed for classical rabies give effective protection (Lyssavirus Expert Group 1996). They offer only marginal protection from Lagos bat, Duvenhage and European bat virus 1 and 2 and no protection from Mokola virus (Rupprecht *et al.* 1995). At this stage the infectivity of Australian bat *Lyssavirus* to domestic animals and other wildlife is unknown. Its close genomic and antigenic relationship to classical rabies virus suggest that it would be capable of causing fatal illness in humans and most other mammals (Fraser *et al.* 1996; Gleeson 1997). Information about the geographic distribution of bat families with classical rabies and other lyssaviruses is summarized in Table 1.

Table 1. World distribution of families of bats reported with rabies and other lyssaviruses. Drawn from Constantine (1988); Brass (1994); Rupprecht *et al.* (1995).

Family	America	Europe	Asia	Africa	Australia
Pteropodidae	—	—	+(*)	+(**)	+(**)
Emballonuridae	+(*)	—	+	+	+(**)
Nycteridae	—	—	+	+(**)	—
Rhinolophidae	—	+(*)	+	+	+
Noctilionidae	+(*)	—	—	—	—
Mormoopidae	+(*)	—	—	—	—
Phyllostomidae	+(*)	—	—	—	—
Vespertilionidae	+(*)	+(*,**)	+	++	
Molossidae	+(*)	+	+	+	+

+family occurs on landmass. *classical rabies. **non-rabies *Lyssavirus*.

DISEASE CAUSED BY LYSSAVIRUSES IN HUMANS AND DOMESTIC ANIMALS

Infection with classical rabies and the other lyssaviruses is usually spread by the bites of animals carrying the disease (Brass 1994; Fishbein and Bernard 1995). Despite folklore of human vampires in some countries (Hand 1984), human to human transmission of the disease is virtually unknown. The virus is shed in the saliva of infected animals, but can also be found in many of the body organs and animals can contract the disease by eating other infected individuals (Afshar 1979). There are four known cases of human rabies infection by inhalation of aerosolized virus in confined spaces with little or no air movement and high concentrations of virus, such as bat caves (n = 2) and laboratories (n = 2) (Brass 1994). Some species of animals left in arthropod-proof cages in caves containing rabid bats have also become infected (Constantine 1988). Scratches are capable of resulting in disease transmission if saliva from an infected animal is also present, but this route of infection is uncommon (Kureishi *et al.* 1992). One case of a person contracting the disease from being licked by a rabid animal has been recorded (Fishbein and Bernard 1995). Of particular concern in relation to bat-human interactions is the finding that of the 28 cases of human rabies in the USA since 1980, 15 have been linked to bat-borne variants of the virus, but in only seven cases could contact with a bat be identified. The bites of insectivorous bats are relatively small and less likely to be noticed than those of larger animals, but this finding suggests that limited physical contact with a rabid bat may be associated with virus transmission in some circumstances (Anon. 1996; Morimoto *et al.* 1996), perhaps lending credence to some of the folklore about the connection between bats and human illness.

In humans the incubation period of rabies (the time from exposure [=bite] to the first symptoms) is usually within 30–90 days of the original exposure, although there are a few cases on record of periods exceeding six years (Faoagali *et al.* 1988; Bek *et al.* 1992; Fishbein and Bernard 1995; Krebs *et al.* 1995). In 95% of human rabies cases symptoms develop within one year of exposure (Fishbein and Bernard 1995). The course of the disease caused by the other lyssaviruses is similar, although this statement is based on very few documented cases. Symptoms of rabies in humans are very variable, but can include fever, headache and behavioural changes, including hydrophobia, hallucinations and paralysis. Once symptoms develop death is almost inevitable (only a handful of cases survive) and occurs within a few weeks of their onset (Brass 1994; Fishbein and Bernard 1995; Krebs *et al.* 1995; Revilia *et al.* 1995).

Most mammals can become infected with rabies, although species vary greatly in their susceptibility. Some, such as foxes, coyotes, wolves and jackals are highly susceptible, while others, such as the American Common Opossum *Didelphis marsupialis* appear resistant to infection (Fishbein and Bernard 1995). Marsupials from Papua New Guinea are more prone to experimental rabies infections than *D. marsupialis* (Gerring *et al.* 1995, pp. 208). Much of the early research in this field assumed that rabies was rabies, irrespective of the animal vector involved or the geographic location. The application of modern molecular techniques has shown that there are many different forms of rabies, each associated with a particular primary host species (reservoir species); many are also restricted to particular geographic areas (Baer and Smith 1991; Smith *et al.* 1992). In the USA, for example, skunk-associated rabies dominates in the central north, whereas in the eastern states the strain present is hosted primarily by raccoons (Krebs *et al.* 1995). Rabies of raccoon origin, for example, can be passed to other species, such as skunks or humans, but in these cases the infection is generally a "dead end" for both the virus and the animals to which it is passed. The infectivity and virulence (impact on host) of the different strains vary greatly, depending on the species involved.

In the same way, particular strains of bat-borne (non-terrestrial) rabies tend to be restricted to particular species of bat. The reservoir host species of non-terrestrial strains are bats, although dead-end exposures can occur in many other species, including humans, domestic animals and wildlife (Brass 1994). It is now possible to determine the particular strain of rabies involved in a human (or animal) illness and, hence, it is possible to reveal a great deal of information on the ecology of the disease. The bat variant responsible for the majority of recent human cases in the USA circulates primarily in populations of the Silver-haired Bat *Lasionycteris noctivagans* although it has recently been isolated from a Red Bat *Lasiurus borealis* that subsequently infected a human (Anon. 1995). Further work in this area will, no doubt, lead to a much deeper understanding of the disease and to improved protection of human and animal health (Krebs *et al.* 1995; Morimoto *et al.* 1996).

One can expect, therefore, that if Australian bat *Lyssavirus* is an old established disease (see Lyssavirus in Australia — whence and when? below) and is like its relatives in other countries, it will probably depend on one or a few species of bat for maintenance and transmission. It is unlikely to establish in populations of terrestrial species, such as dogs and foxes, even though "dead-end" infections may occur in such species, in other bats and in other species of wildlife. The animal from which the human victim contracted the disease will probably never be known, as the victim was bitten by many animals, including Common Brushtail Possums *Trichosurus vulpecula*, two species of flying fox and a microbat. Potential carriers had all been euthanased or released before testing could be done. The molecular evidence, however, indicated that the virus responsible for her death probably came from a Black Flying Fox (L. Gleeson, unpubl.).

PEOPLE AT RISK AND PREVENTION OF THE DISEASE

Education of the public about the risks of contact with bats (and perhaps other wildlife) is the single most important action that can be take to minimize the human health risk and the potentially substantial cost of prevention (Brass 1994; Krebs *et al.* 1995; Rupprecht *et al.* 1996). Children are especially at risk (Kureishi *et al.* 1992; Fishbein and Bernard 1995). The current public view both urban and rural, Aboriginal and non-Aboriginal, that Australian wildlife is totally benign needs to be modified to minimize the risk of people becoming infected with *Lyssavirus* (and probably other zoonoses) through contact with infected animals.

Aboriginal people in northern Australia eat flying foxes in large numbers (McKnight 1975; Altman 1987; Baker 1988; Vardon *et al.*, in press), although there appears to be no traditional knowledge of a rabies-like illness following bites (Warner 1937; Berndt and Berndt 1989). In Nigeria, where classical rabies and two other lyssaviruses are present, the indigenous people hunt bats in large numbers (Folorunso and Okpetu 1975), but they also believe that if a bat bites a person, then madness and death ensue (Aghomo *et al.* 1990). Traditional knowledge of a rabies-like malady is widespread among native people throughout the Pacific Northwest (Winkler 1975) and in Central and South American countries where vampire-borne rabies is prevalent (Brass 1994). One group of indigenous South Americans is known to hunt bats, including Vampire Bats *Desmodus rotundus* (Setz and Sazima 1987). Rabies virus is destroyed by cooking at 54°C for 30 minutes or 35 seconds at 60°C (Fishbein and Bernard 1995) and cases are known of people eating cooked rabid dogs with no ill-effect, while individuals who butchered the carcases contracted rabies (Kureishi *et al.* 1992). There is a clear need for the Australia Aboriginal population to be educated about the potential dangers of contact with live or uncooked bats. Since about 3 500 years BP dingoes have been companions of Aboriginal hunters (Corbet 1995) and incidental infection of dingoes from infected bats could also pose a health risk in Aboriginal communities.

Australian fruitgrowers are another group that needs to be educated about the dangers of bat-borne disease. Many thousands of flying foxes are destroyed annually, usually by shooting, on fruit crops on the east coast of Australia (Vardon and Tidemann 1995) and in some areas of the Northern Territory and Western Australia (Tidemann, unpubl.; Vardon, unpubl.; Nelson, unpubl.). Dogs are commonly present during "bat-shoots" and foxes in many of these areas scavenge dead and dying bats. Flying foxes commonly bite fruit other than those they consume (Tidemann and Nelson 1987). Because the virus is destroyed by exposure to sunlight and drying (Fishbein and Bernard 1995), saliva on the surface of fruit is unlikely to remain viable for long. The virus is also destroyed by acidity (pH of 3 or less), so is unlikely to survive in the flesh of fruit, which is usually acidic (Biale and Young 1981).

The minimal contact, sometimes with no evidence at all of bites, that is known to result in human rabies of bat origin in the USA (Anon 1996) suggests that any contact between the public and bats should be minimized. This would include discouraging people from unnecessarily entering bat caves and preventing contact between bats and humans co-occupying buildings (e.g., Tidemann and Flavel 1987). It suggests also that live bats should not be allowed to come into contact with the public during, for example, educational sessions (Hutson 1996) or at zoos, unless the animals have been vaccinated against lyssavirus.

People, such as bat researchers or animal rehabilitators, who come into frequent contact with bats (or other possibly infective animals) should avoid bites and other contact with virus by wearing protective clothing (Lyssavirus Expert Group 1996). Protective clothing for handling large flying foxes should include steel mesh gloves (Tidemann and Loughland 1993). People at risk of exposure to *Lyssavirus* should also receive pre-exposure vaccination, which involves three injections at a total cost of about $AUS300. Immediate washing of bites with soap or detergent is recommended if exposure, such as a bite from an infected animal occurs, followed soon after by post-exposure vaccination (Lyssavirus Expert Group 1996).

Post-exposure treatment is expensive (about $AUS800–1,000). Because of the application of pre and post-exposure treatment in the USA and Europe only a few deaths from rabies are reported each year (Rupprecht *et al.* 1995), but the cost makes its use prohibitive in many poorer countries. In the USA the annual bill for human rabies treatment is $US45 million ($AUS56 million), because infection in a single person can lead to dozens of "exposed" people also requiring treatment (Anon. 1995). Recent examples in the USA include 99 people treated in Arkansas as the result of a single human infection (Gonzales *et al.* 1991), 83 in Connecticut (Munoz *et al.* 1996) and 76 in California (Falade *et al.* 1996). Each of these incidents would have cost more than $AUS70,000 for the vaccine alone. It is clearly in the public interest to minimize contact between people and bats in Australia, not only because of the health risks, but also because of the potentially large cost to the public purse. There is also a very real risk of a public backlash against bats if people are seen to contract fatal diseases from them. Only when more is known about the infectivity of Australian bat *Lyssavirus* to people and other mammals will it be prudent to decrease vigilance.

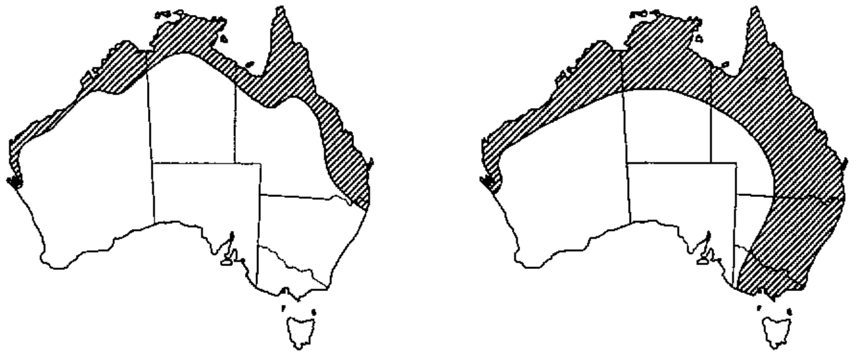
LYSSAVIRUS IN AUSTRALIA — WHENCE AND WHEN?

Australia, partly because of its relative isolation and partly because of its quarantine procedures, has remained free of rabies and many of the other horrific zoonoses that plague much of the rest of the planet. There have been three recorded human cases of rabies in Australia, but all resulted from the virus entering the country from another landmass. A child in Tasmania is thought to have contracted the disease from a rabid dog in 1867 (Dunn *et al.* 1988; Geering *et al.* 1995), while two children, one in 1987 and another in 1990, contracted the disease while travelling overseas, presumably from contact with rabid animals (Faoagali *et al.* 1988; Bek *et al.* 1992). Australia is classified as rabies-free (Geering *et al.* 1995).

Australian bat *Lyssavirus*, first isolated from a Black Flying Fox, has now been identified in two other flying fox species and an insectivorous bat from widely separated locations in Australia (Fig. 1). All four species have wide distributions (Fig. 2). The current extent of *Lyssavirus* in Australia and it origins are, however, unknown (Gleeson 1997). At this stage is seems prudent to assume that it could extend across the whole continent and could be present in any or all of the 70 or so species of bat that inhabit Australia (Strahan 1995). Strongly colonial species, such as the large flying foxes and some of the cave-dwelling microbats may provide populations in which the virus could become amplified, but it is worth noting that the most common strain causing human rabies in the USA circulates in the Silver-haired Bat *Lasionycteris noctivagans*, a solitary and relatively uncommon species (Anon.1996). The Yellow-bellied Sheathtail Bat, one of the Australian species found infected with Australian bat *Lyssavirus*, shares similar habits (Richards 1995).

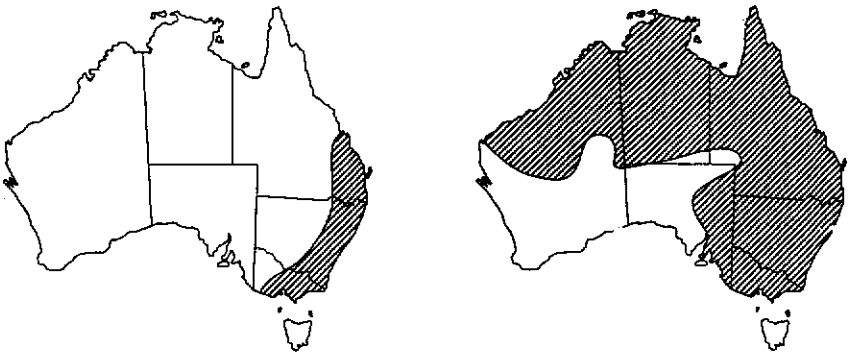
The earliest known case of Australian bat *Lyssavirus* is from January 1995 in Townsville, but it is unknown if the disease has been present in the country for a long time, like the so-called equine morbillivirus (= bat paramyxovirus) (Allworth *et al.* 1995; Young 1996), or if it is a recent entry. The fact that there is no tradition among Aboriginal people who have hunted flying foxes for many thousands of years and the very large number of non-Aboriginal people, particularly in eastern Australia, who have had close and frequent contact with bats, particularly flying foxes, over the last 20 years, suggest either that the disease is a new occurrence in Australia or that it is not very infective to humans. But, it is worth noting here that bat-borne rabies was not identified in the USA until 1953, nor in Europe until 1954 (Rupprecht *et al.* 1995). However, classical rabies is prevalent on both continents and bat-borne occurrences of the disease may well have been masked by the much more common source of infection — terrestrial animals. It is possible that Australian bat lyssavirus has been present primarily as a disease of microbats and has only recently entered the flying fox population through unusual circumstances. Only further testing and analysis will provide a definitive answer.

Another possibility is that Australian bat *Lyssavirus* is a recent entry to the continent, in which case one could expect a progressively increasing risk of infection to the human



Pteropus alecto
Black Flying Fox

Pteropus scapulatus
Little Red Flying Fox



Pteropus poliocephalus
Grey-headed Flying Fox

Saccolaimus flaviventris
Yellow-bellied Sheathtail Bat

Figure 2. Australian distribution of the four species of bat found infected with Australian bat *Lyssavirus*.

population and to other animals (Gleeson 1997). Black Flying Foxes are highly mobile animals and extend beyond the Australian continent to New Guinea and some of the Indonesian islands including Sulawesi (Flannery 1990; Kitchener *et al.* 1990; Mickleburgh *et al.* 1992; Webb and Tidemann 1996). Black Flying Foxes are also known to move, on a more or less regular basis, between New Guinea and the islands in Torres Strait (G. C. Richards, pers. comm.). It is conceivable that the disease could have entered Australia by this route. Little Red Flying Foxes also are highly mobile animals and have been recorded from southern New Guinea, Ashmore Islands, 350 km to the north-west of Australia (Fig. 2) and one individual has even reached New Zealand (Sinclair *et al.* 1996). The Common Bent-winged Bat *Miniopterus schreibersii*, is a species with a world-wide distribution (Dwyer 1995) and some animals may move between Australia and neighbouring landmasses. Searches for lyssaviruses in bats on landmasses adjacent to Australia would enable evaluation of this hypothesis.

Papua New Guinea and Irian Jaya are ostensibly *Lyssavirus*-free, but the potential for such diseases to go unnoticed by health authorities in developing countries is probably substantial. Terrestrial rabies, for example, has been reported recently in Flores (R. Noske, pers. comm.) and, considering the existence of several forms of non-rabies lyssaviruses in Europe and Africa and now one in Australia, it seems probable that bat-borne lyssaviruses are also present in South-East Asia. Movements of bats within the Australian continent are not well understood. Available information on movements of flying foxes (Ratcliffe 1931; Nelson 1965; Eby 1991; Webb and Tidemann 1996) suggests that the patterns are climate-controlled, but the domination of the climate of eastern Australia by the El Niño-Southern Oscillation phenomenon (Nicholls and Kariko 1993) means that the cycles are long-term. Concurrently, the rainfall of eastern Australia has increased over the last 50 years (Nicholls and Lavery 1992). Patterns of animal movement controlled by such phenomena are not readily elucidated by short-term studies.

Movement of animals and their diseases can also be affected by human activities such as vegetation clearing and deliberate translocations. The range of the Black Flying Fox has extended down the east coast of Australia by about 500 km in the last 50–60 years (Webb and Tidemann 1995), possibly influenced by large-scale changes to vegetation patterns through clearing (Biodiversity Unit 1995). Deliberate movements of animals by people are also known to have changed the distribution of diseases; movement of asymptomatic but rabid animals has changed the epidemiology of rabies in the USA (Krebs *et al.* 1995; Rupprecht *et al.* 1995). A North American bat, *Eptesicus fuscus*, imported into Germany from Canada for scientific study, was found to be rabid (Brass 1994, pp. 276) and several *E. fuscus* shipped from the US to Denmark for study were subsequently found to be infected (Rupprecht *et al.* 1995). Sasaki *et al.* 1992 reported a rabid *E. fuscus* that was accidentally transported from continental USA to Hawaii in a shipment of cars. None of these latter cases resulted in the establishment of rabies, but they illustrate how the actions of well intentioned but ill-informed people can lead to unintended movements of diseases, quite apart from the usually undesirable impact on the genetic integrity of populations.

CONCLUSIONS

The discovery of Australian bat *Lyssavirus* poses new problems for public health authorities and wildlife managers. An education programme is urgently needed to carry, in parallel, information on the conservation benefits of bats and actions to minimize the public health risks. It is vital, in designing this process, that there is collaboration between relevant specialists and consultation with at-risk groups of the public. Research is needed to understand the epidemiology of the disease and its infectivity to people and other mammals so that the actual as opposed to potential risks can be assessed. It is particularly important that bat specialists collaborate with local health and agriculture professionals in the identification of bats submitted for pathogen diagnosis, as has been emphasized recently in the US (Anon. 1995b) and the United Kingdom (Hutson 1996). This will be even more important in Australia because of the far greater number of bat species and the complexity of their ecology. The emergence of Australian bat *Lyssavirus* has very clearly highlighted the almost *ad hoc* management of bats, responsibility for which is fragmented between a host of state/territory and Commonwealth agencies concerning wildlife, agriculture, health and quarantine (Tidemann and Vardon 1997). It is important that such problems be resolved if these ecologically important animals are to be effectively conserved.

ACKNOWLEDGEMENTS

We wish to acknowledge special thanks to Helen Luckhoff and Julie Spence for their assistance over many years and to the following for their help in assembling the information presented in this paper: David Adams, David Blair, Chris Bunn, Debbie Claridge, Roger Coles, Margaret Clunies-Ross, Warren Entsch, Evelyn Gough, Dinah Hansman, Tony Hutson, Ann Johnson, Bruce Johnson, Shannon Kelson, Monica Jones, Len Martin, Julie Morrison, Ann Munster, Gemma O'Brien, John Padget, Shona Peters, Bill Rainey, Iris Selby, Sonya Stanvic, Ian Temby, Pam Tully, Dianne Vavryn, Josef Vavryn and Wendy Lees. Ann Biasol, Danny Brass, Dan Lunney and three referees provided very useful comments on earlier drafts of this paper.

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